Trapping Particles of Darkness

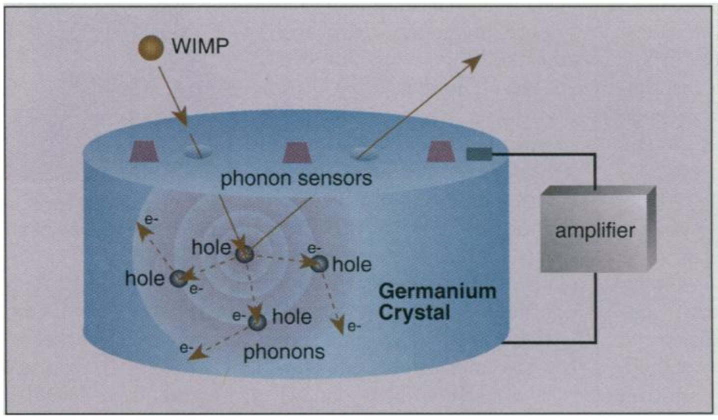
Armed with sensitive detectors, researchers are retreating to mines and tunnels to find the exotic particles that may flesh out the universe

Cosmologists speculate that we live in a dense sea of invisible particles. Millions of them stream through your body each second. You can't escape them, but they can't hurt you—they're only WIMPs, Weakly Interacting Massive Particles. But WIMPs deserve some respect: Their combined mass may hold together galaxies and clusters of galaxies and even keep the universe from expanding forever. And that's why scientists around the world are casting their nets, eager to see if these elusive particles really exist.

Finding WIMPs and other "dark matter" particles will take some tough sleuthing. Most such particles, unable to exert or respond to the nuclear or electromagnetic forces, would pass unobtrusively through air, water, rock, and almost any detector scientists can envision. But with luck and a sensitive enough instrument, well shielded from interfering signals, investigators think they might glimpse an occasional dark matter particle—one in billions—as a flash of light, an electrical blip, or a vibration. Indeed, they're so optimistic now that the search has turned into an international race. In England, Peter Smith of the Rutherford-Appleton Laboratory is within months of starting his WIMP hunt. At the University of California, Berkeley, a group led by Bernard Sadoulet is busy testing and perfecting the detectors they plan to bury in an underground facility at nearby Stanford University this winter. And European researchers are setting competing experiments in the Gran Sasso road tunnel in the Apennine Mountains of Italy.

Could these groups be hunting particles that don't exist? Perhaps. But while the argument supporting WIMPs is highly theoretical, it's convincing enough that most astrophysicists say that the search is worth the effort. The case for WIMPs rests mostly on many theorists' belief that the universe must have enough mass that gravity will eventually put the brakes on its expansion, poising it right on the edge between collapse and growth to infinity. For example, a current favorite picture of the early universe known as the inflationary model requires that the universe must have had—and still has—exactly the "critical density" that would balance it between these two extremes.

But the longing for critical density has to contend with an awkward fact: The universe suffers from a serious shortfall of ordinary matter, consisting of protons, neutrons, and electrons. In the 1970s, explains University of Chicago cosmologist David Schramm, researchers calculated how dense the newborn universe must have been to account for the relative amounts of helium and deuterium forged in the Big Bang. The answer, says Schramm, implies that the universe today contains about one-tenth as much ordinary matter as the critical density. For theorists to have their critical density, 80% or 90% of the mass in the universe would have to be something else, pervasive yet aloof from detection by ordinary means.



Signature of a WIMP. The Berkeley detector will watch for a pulse of ionization and subtle vibrations called phonons.

Silent partners

Astronomers may soon have more direct evidence that such exotic dark matter exists. By measuring how fast galaxies move within clusters, astronomers are "weighing" big chunks of the universe—learning how much mass must be pulling on the galaxies. So far, says Edmund Bertschinger of the Massachusetts Institute of Technology, the results show there is definitely more matter than meets the eye. Much of that extra stuff, maybe all, could be some obscure form of ordinary matter—rocks, planets, dust, or dim stars. But if the observations show that galaxies are moving under the sway of more mass than the helium and deuterium measurements allow—and Bertschinger says some observers may soon be exceeding the limit—astronomers may have to conclude that some exotic form of matter is also stirring the pot.

Such exotica could come in the form of known particles called neutrinos, but only if current experiments show they carry a mass—and so far the results have been inconclusive. If neutrinos won't fit the bill, theories of particle physics offer two other candidates. One, dubbed the axion, falls out of an attempt to solve a vexing asymmetry between the properties of matter and antimatter. The other, the WIMP, is a child of a popular theory known as supersymmetry, which postulates that every known particle has a massive supersymmetric partner. The most likely candidate for balancing the mass of the universe is the lightest and most stable of these WIMPs, the photino—partner of the photon.

Theorists say the next generation of accelerators—Europe's Large Hadron Collider and the United States' Superconducting Super Collider, if it is funded—could uncover signs that these supersymmetric partners exist. The most massive of them might materialize briefly in high-energy collisions. But the lightest, stablest WIMPs—the ones most likely to act as dark matter particles—would elude the accelerator detectors. The only way to find them, say the dark matter searchers, is to design new instruments that can watch, wait, and catch them in their natural form.

The same is true for axions. Researchers at Brookhaven National Laboratory recently launched the first axion search. The way to snare an axion, says Michael Turner of Fermilab, is to generate a powerful magnetic field, then watch for a blip of radiation. "A magnetic field changes an axion to a photon," he explains, and the photon's frequency reveals whether it originated in an axion. The Brookhaven group didn't find axions but did set an upper limit to their mass; researchers at the University of Florida are now planning a bigger search that will have a better shot at the real thing.

But while scientists agree on one basic technique for detecting axions, there's no consensus about the best way to catch a WIMP. As a result, competing groups are springing up in different parts of the world, each with its own favorite strategies. England's Smith hopes to be the first to succeed.

"I'm a competitive person," he admits. "There is a lot of credit for reaching something first." But two daunting problems are forcing him to start small. A WIMP would move through the material of any detector like a bullet in a difficult shooting gallery, rarely touching a target. Unaffected by the forces that act on ordinary matter, the WIMP would register in the detector only when it ricocheted directly off a nucleus or an electron. That means that any WIMP detector will have to search for a faint signal. And—problem number two—the search will have to take place against a dense background of misleading events, created by cosmic rays and natural radioactivity. No one design is certain to work, so Smith is working on designs for a half-dozen different detectors. Among the furthest along, he says, is a cylinder-shaped crystal of sodium iodide that would record a flash of light—called a scintillation—if hit right in a nucleus or electron by a WIMP. If all goes well, he says, that detector might capture about one WIMP count per day.

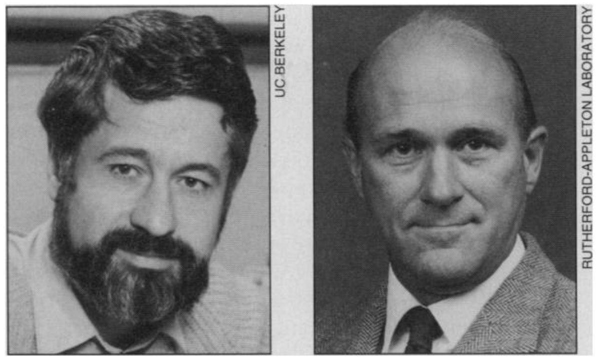
Sorting WIMPs from chaff

To avoid swamping the detectors with cosmic rays, Smith plans to stage his WIMP watch 1100 meters underground at the bottom of a salt and potash mine on the northeast coast of England. And to protect them from natural radioactivity in the rocks, he will shield them with hundreds of tons of pure water. But even the materials in the detectors will generate confounding signals. "Most materials are 10,000 times as radioactive as you can tolerate," he says.

Because these problems are so frustrating, Smith says he will launch his dark matter search in two stages. In the first stage, he explains, "We can make a start and learn something about the background, about the materials, about working in the mine." For the second stage he will use detectors with the ability to sort out more of the background junk from his real signal. His competitors in Berkeley and Gran Sasso, however, are plunging ahead to this second stage, hoping to snare conclusive results.

The Berkeley group was encouraged to take this bold approach by their discovery last spring that they can filter out most of the background events by searching simultaneously for two different WIMP signals in crystals of germanium. One test involves the detection of vibrations, or phonons, triggered by passing WIMPs. To pick up these faint signals, the Berkeley group cools the crystals to 20 millikelvin—just above absolute zero. The cold makes the detectors sensitive to the minute vibrations that should result if a WIMP blunders into a nucleus or electron. The second test looks for a small pulse of ionization that should also traverse a crystal when a passing WIMP nudges an electron or a nucleus.

In combination, says Berkeley team member Tom Shutt, these signals can distinguish real dark matter sightings from most of the unwanted background events. The key, explains team member Betty Young, is the proportion of phonons to ionization. That value changes depending on whether the intruding particle has ricocheted off a nucleus or an electron in the crystal. WIMPs should create a high nucleus-hit value, and background radiation, a high electron-hit value.



WIMP hunters. Bernard Sadoulet of Berkeley *(left)* and Peter Smith of England's Rutherford-Appleton Laboratory.

The Berkeley scientists recently demonstrated this discriminating ability by comparing their detector's response to a beam of neutrons (surrogates for WIMPs) and natural radioactivity. The test showed that the sensor was able to tell the difference between the two. With that breakthrough, Young says, she and her colleagues are within months of setting up the equipment. At least at first, they won't be going as deep underground as Smith; their early runs will take place in a 20-meter-deep hole at Stanford. With the detectors' powers of discrimination, Young says, that should be deep enough "to get a really meaningful experiment."

Other groups around the world are edging up to the starting line. Another entrant in the race is a group of Stanford scientists who will be sharing an underground facility with the Berkeley group, says Young. The Stanford team, led by physicist Blas Cabrera, has devised yet another kind of detector, based on silicon crystals coated with fine lines of superconducting material that should lose their superconducting ability, or "go normal," with the slightest nudge in temperature—even just the whisper of a WIMP. Yet another entrant is a group from the University of Milan, led by Ettore Fiorini. Its detector, already set up at Gran Sasso, is designed mainly to detect a rare radioactive process known as double beta decay, but Fiorini says that the device might also be sensitive to WIMPs.

Once the detectors are in place in their mines and tunnels, the waiting game will begin. "It could take 10 years," says Smith. But one brush with a WIMP, he says, would make it all worthwhile. To get a sense of why, says MIT's Bertschinger, "remember all the elation surrounding the results from the Cosmic Background Explorer," the satellite that recently found unevenness in the pervasive background of microwaves believed to come from the Big Bang. "This will be four times as big," he says. "It will reveal to us the dominant component of matter in the universe."

"It would change physics," adds Fiorini. "I don't even dare to have such a hope." Like the others, Smith says he tries not to think too hard about the rewards. He recalls a story about a famous tennis player who played in the Wimbledon match and lost because he started thinking about his victory speech while still in the game. Smith says he wants to avoid that folly. "You don't think about winning until you've actually won."

–Faye Flam

INTERNATIONAL COOPERATION

A Match Made in Laser Heaven

As the world watched the dramatic political changes unfolding in the former Soviet Union over the past year, the last thing on the minds of most onlookers was how the upheaval might affect laser technology. But for physicists John Madey at Duke University and Vladimir Litvinenko, formerly of the Budker Institute of Nuclear Physics in Novosibirsk, Russia, the fall of communism may lead to a scientific dream come true—the opportunity to speed up development of what they hope will be the world's first tunable laser capable of operating in the very high ultraviolet (UV) and possibly even the x-ray range.

Today, after months of negotiations, Duke officials announced an agreement to bring a so-called free electron laser developed by Litvinenko and his colleagues in Novosibirsk to Duke, where it will be joined to an accelerator, developed by Madey and his colleagues, that would boost the laser's operating range into the far ultraviolet. If funding can be found to finance the move, the partnership should shave 2 years off the time it would have taken the Duke team to produce a tunable UV laser on its own, says Madey. He predicts that the machine will be up and running before the end of 1994, although that may not be soon enough to beat out some stiff competition from the big national labs at Los Alamos and Brookhaven, which also have tunable UV lasers under construction. Madey says those machines will have different technical capabilities and objectives, however.

But wherever a tunable UV laser comes from, it would be widely welcomed by both chemists and medical researchers. Although some conventional lasers operate in the high UV and x-ray ranges, no single conventional laser can operate over the entire range, which